Crop Residues:

Why They Should Be Buried Rather Than Burnt, from a Carbon Perspective

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Background

- Farming is mankind's largest scale activity, occupying 10% of the land area of the Earth
- Crop residues usually comprise 1.5 kg biomass per kg of harvested product
  - 0.24 Gt crop residue carbon (CR C) produced annually in US maize, soybean and wheat crops
  - Globally, about 1 Gt CR C available annually
    - One fourth of the annual increase in atmospheric carbon due to anthropogenic sources
    - Man-made atmospheric CO_2 increases by about 4 Gt C annually

This entire slide is lifted out of
Metzger and Benford, 2001, Sequestering of atmospheric carbon through permanent disposal of crop residue, Climatic Change **49**, 11.

How Best to Use Crop Residues to Reduce Atmospheric Carbon Dioxide?

- Currently crop residue carbon returns to the atmosphere as residues rot on the ground
- Current plans are to use crop residues to produce cellulosic ethanol for use as fuel
- But is cellulosic ethanol production the most efficient use of crop residues?

The Alternative:
Crop Residue Ocean Permanent Sequestration — CROPS

- 75% of crop residue available
- Collect and bale
- Transport by truck to rivers
- River and ocean barge to off-shore site with depth greater than 1500 m
- Ballast with limestone
- Sink and monitor

Objectives

- Calculate the efficiency of fossil fuel carbon emission reduction by conversion of crop residues to cellulosic ethanol
  - How much fossil fuel carbon emissions is avoided per ton of crop residue carbon?
- Calculate the efficiency of carbon sequestration of Crop Residue Ocean Permanent Sequestration (CROPS)
  - How much carbon can be removed from the atmosphere by burying crop residues in deep ocean sediments?
  - How much fuel must be burned to transport crop residues to deep ocean?
- **Carbon Sequestration Efficiency** calculated for each process:

$$CSE = \frac{Carbon\ sequestered + Fossil\ fuel\ C\ emissions\ avoided}{Crop\ residue\ C\ processed}$$

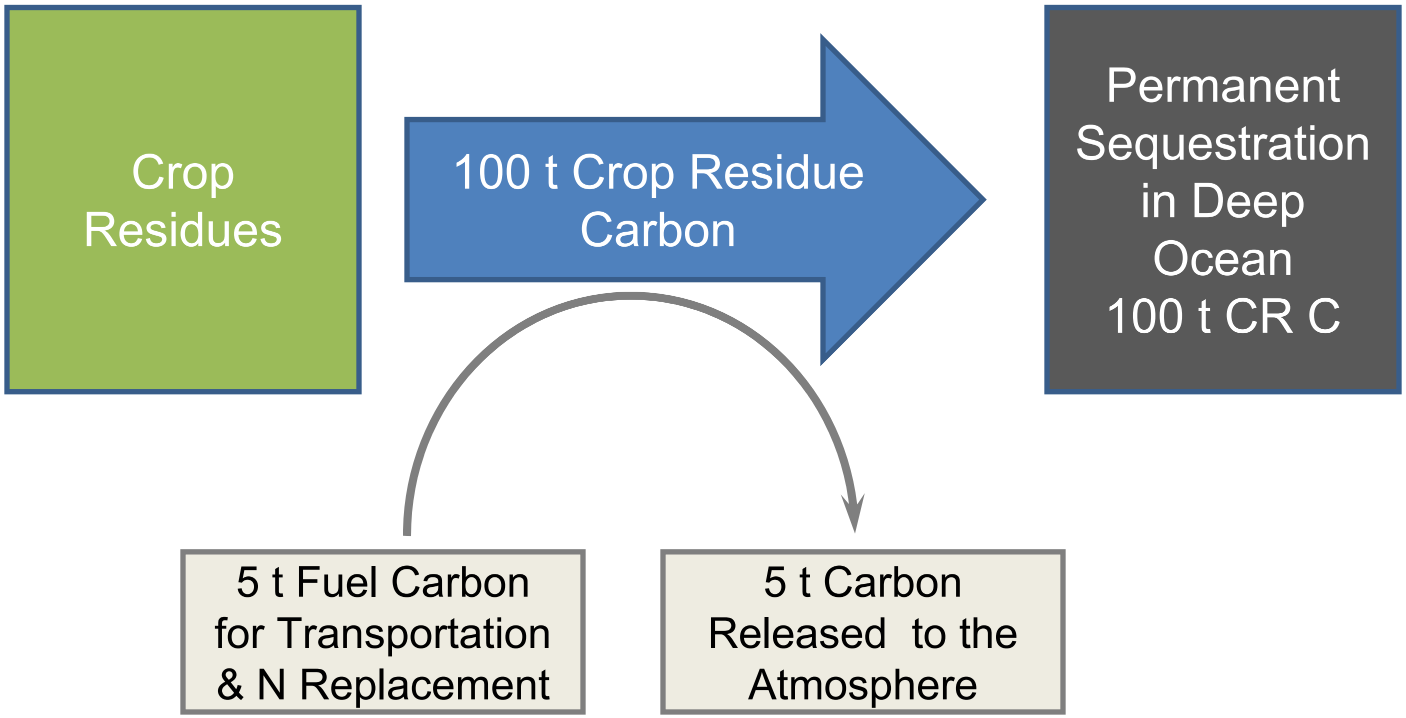
Carbon Emitted From Fuel Use During Crop Residue Ocean Permanent Sequestration (CROPS)

Baling, including harvesting					3.50	L diesel/t CR
Transportation to barge by tractor trailer	200	km	38.5	net t CR km per L diesel	5.19	L diesel/t CR
River barging	1000	km	231	net t CR km/L diesel	4.33	L diesel/t CR
Ocean barging,with ballast surcharge (2.7X)	1000	km	443	net t CR km/L diesel	6.09	L diesel/t CR
Total transportation					15.62	L diesel/t CR
Total diesel oil used					19.1	L diesel/t CR sequestered
Carbon content of diesel					0.73	kg C diesel/L diesel
Carbon emitted from diesel burnt during CROPS					14.0	kg C diesel/t CR sequestered
Fertilizer replacement					9.9	kg C for N/t CR sequestered
Total carbon emitted during CROPS					23.9	kg C emitted/t CR sequestered
Carbon content of CR					45%	t CR C/100 t CR sequestered
Total carbon emitted during CROPS					**5.31**	**t C emitted/ 100 t CR C sequestered**

Carbon sequestration efficiency	**94.7**	**t C removed from atmosphere / 100 t CR C sequestered**

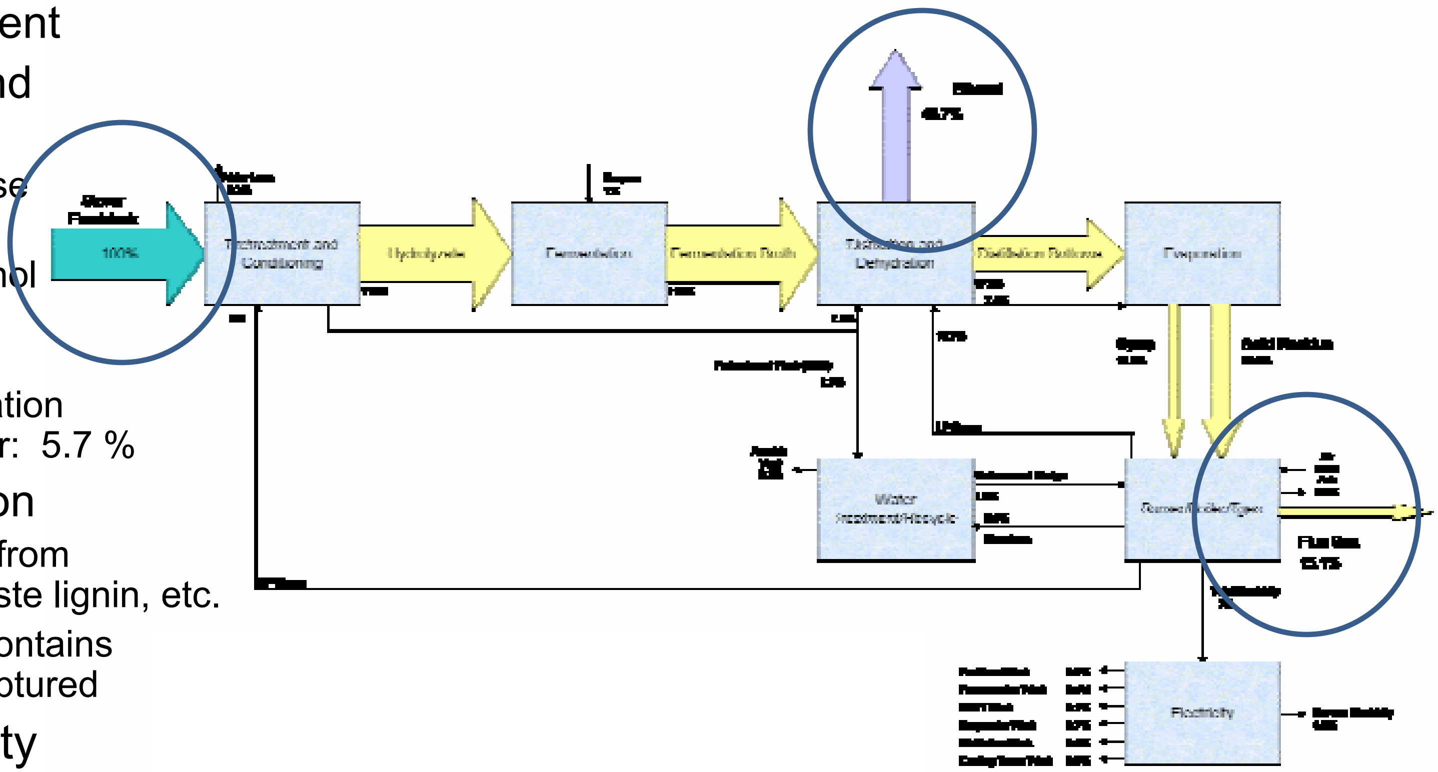
CR = Crop Residue

Carbon Flow for Crop Residue Ocean Permanent Sequestration



Model Crop Residue/Ethanol Production Plant

- Based on Aden et al., 2002, NREL Report TP-510-32438, “Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover”
- Corn Stover input, 38 t CR per hr
- Acidic pretreatment
- Co-hydrolysis and fermentation
  - Glucose and xylose fermentation
  - Efficiency of ethanol production from sugars, 85-95%
  - Ethanol concentration from the fermenter: 5.7 %
- Ethanol distillation
  - Heated by steam from combustion of waste lignin, etc.
  - Ethanol product contains 48% of energy captured
- Excess electricity produced from wastes
  - 15% of energy captured



Carbon Emissions Avoided by Cellulosic Ethanol Production from Crop Residues

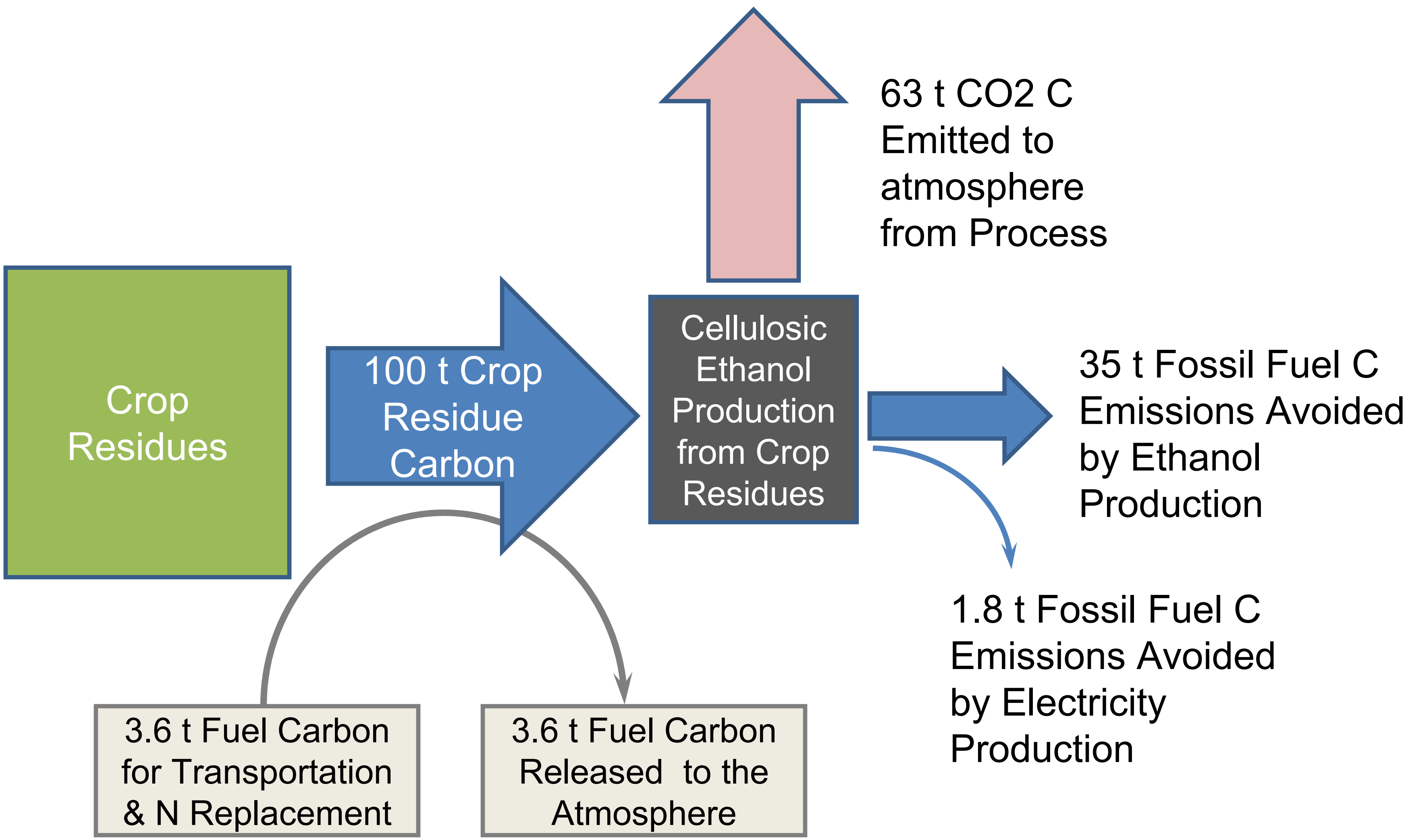
based on Aden et al. 2002, Lignocellulosic Biomass to Ethanol Process Design ... For Corn Stover. NREL/TP-510-32438

Carbon inputs		
Corn stover feedstock, crop residue carbon, CR C	3144	kmol CR C / hr
	37.728	t CR C / hr
Energy outputs		
Ethanol product	1066	kmol ethanol C / hr
Energy density of ethanol	0.17	MW hr / kmol ethanol C
	182	MW hr / hr
Energy density of diesel	11.9	MW hr / t diesel
	13.67	MW hr / t diesel C
Diesel emissions avoided by ethanol production	13.30	t CO2 C from diesel / hr
Excess electricity	2.73	MW hr / hr
CO2 from electricity generation, using petroleum*	0.24	t CO2 C / MW hr
CO2 C emissions avoided by excess electricity	0.67	t CO2 C / hr
Total CO2 C emissions avoided	13.96	t CO2 C / hr
Carbon emissions avoidance efficiency	37.0	t CO2 C emissions avoided /100 t CR C processed
CO2 C emissions during baling and transportation, N replacement		
Baling, including harvesting	3.5	L diesel/t CR processed
Transportation to ethanol plant by tractor trailer	5.2	L diesel/t CR processed
Total diesel use for baling and transportation	8.7	L diesel/t CR processed
Carbon content of CR	0.45	g CR C / g CR
Carbon content of diesel	0.73	kg C diesel/L diesel
C emissions during baling and transportation	1.41	t diesel C / 100 t CR C processed
Fertilizer for N replacement	2.20	t fossil fuel C / 100 t CR C processed
Net carbon emission avoidance efficiency	**33.40**	**t CO2 C emissions avoided / 100 t CR C processed**

*Carbon dioxide emissions from the generation of electric power in the US, DOE and EPA

†200 km, 38.5 net t CR km/L diesel

Carbon Flow for
Celluosic Ethanol Production from Crop Residues

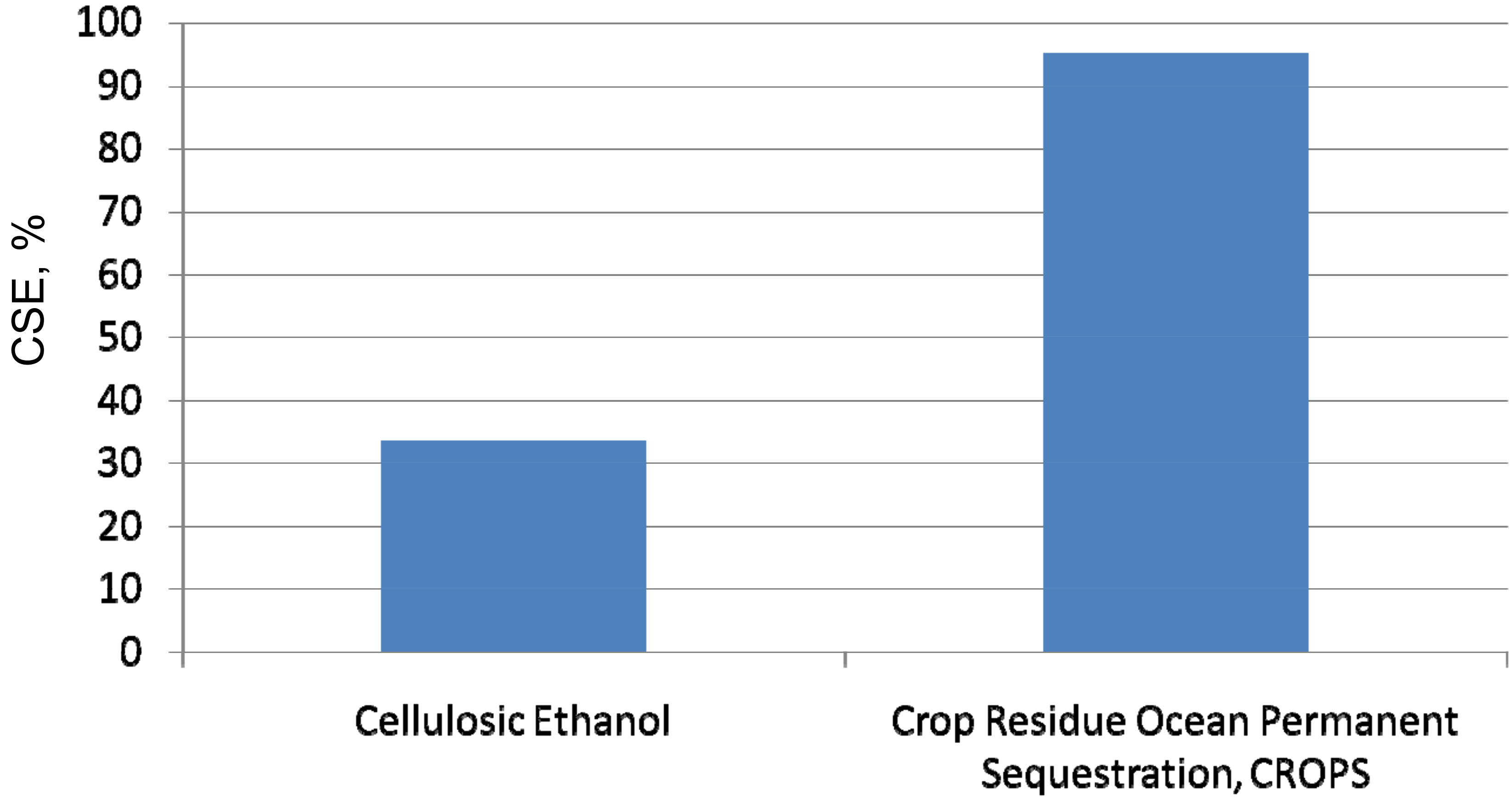


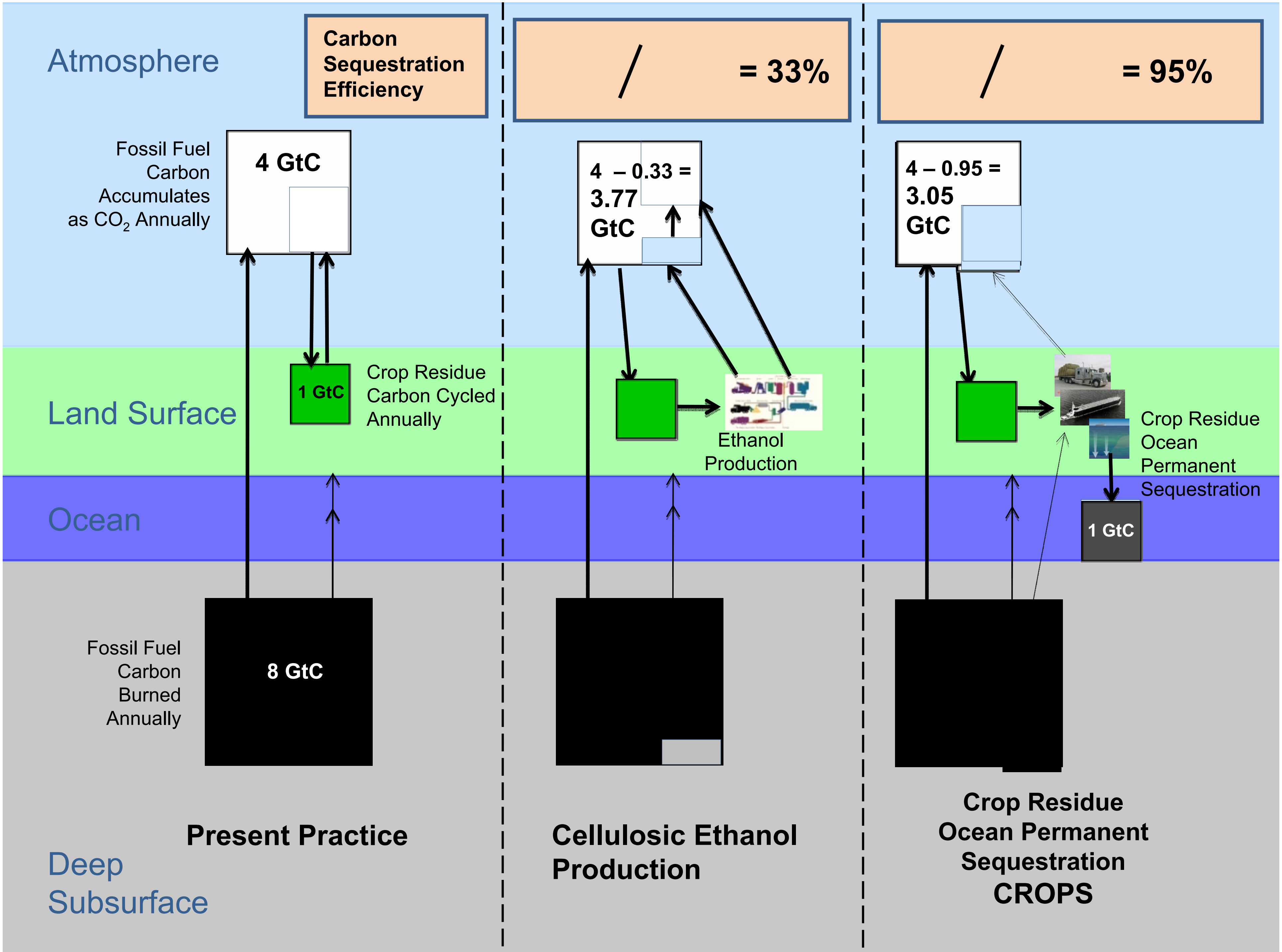
Summary

Carbon Sequestration Efficiency

% of Crop Residue C Harvested That Is Sequestered or Used to Avoid Fossil C Emission to Atmosphere

$$CSE = \frac{Carbon\ sequestered + Fossil\ fuel\ C\ emissions\ avoided}{Crop\ residue\ C\ processed}$$





Atmosphere
Carbon Sequestration Efficiency
/ = 33%
/ = 95%
Fossil Fuel Carbon Accumulates as CO_2 Annually
4 GtC
4 – 0.33 = 3.77 GtC
4 – 0.95 = 3.05 GtC
Land Surface
1 GtC
Crop Residue Carbon Cycled Annually
Ethanol Production
Crop Residue Ocean Permanent Sequestration
Ocean
1 GtC
Fossil Fuel Carbon Burned Annually
8 GtC
Deep Subsurface
Present Practice
Cellulosic Ethanol Production
Crop Residue Ocean Permanent Sequestration CROPS

Advantages of CROPS

- Immediate application
  - Low tech
    - No unproven technologies involved
    - Could be implemented within 2-3 years
  - Each year atmospheric CO_2 accumulation could be reduced by 1 GtC using CROPS
  - 25% reduction of global anthropogenic induced annual increase
  - In 10+ years before demonstration of practical cellulosic ethanol production,

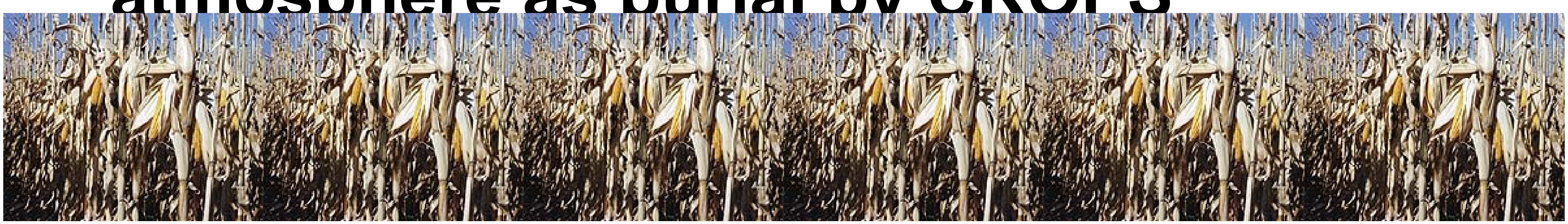
10 GtC could be removed from atmosphere using CROPS before cellulosic ethanol is deployed

- Permanence
  - DOE has set a goal of 0.01% per year for global CO_2 reservoirs
  - Below 1500 m the leakage rate of dissolved CO_2 from ocean sequestration sites would be less than 0.1% per year
    - Burial and recalcitrance of CROPS lignocellulose would likely reduce the leakage rate to near 0.01% per year

Conclusions

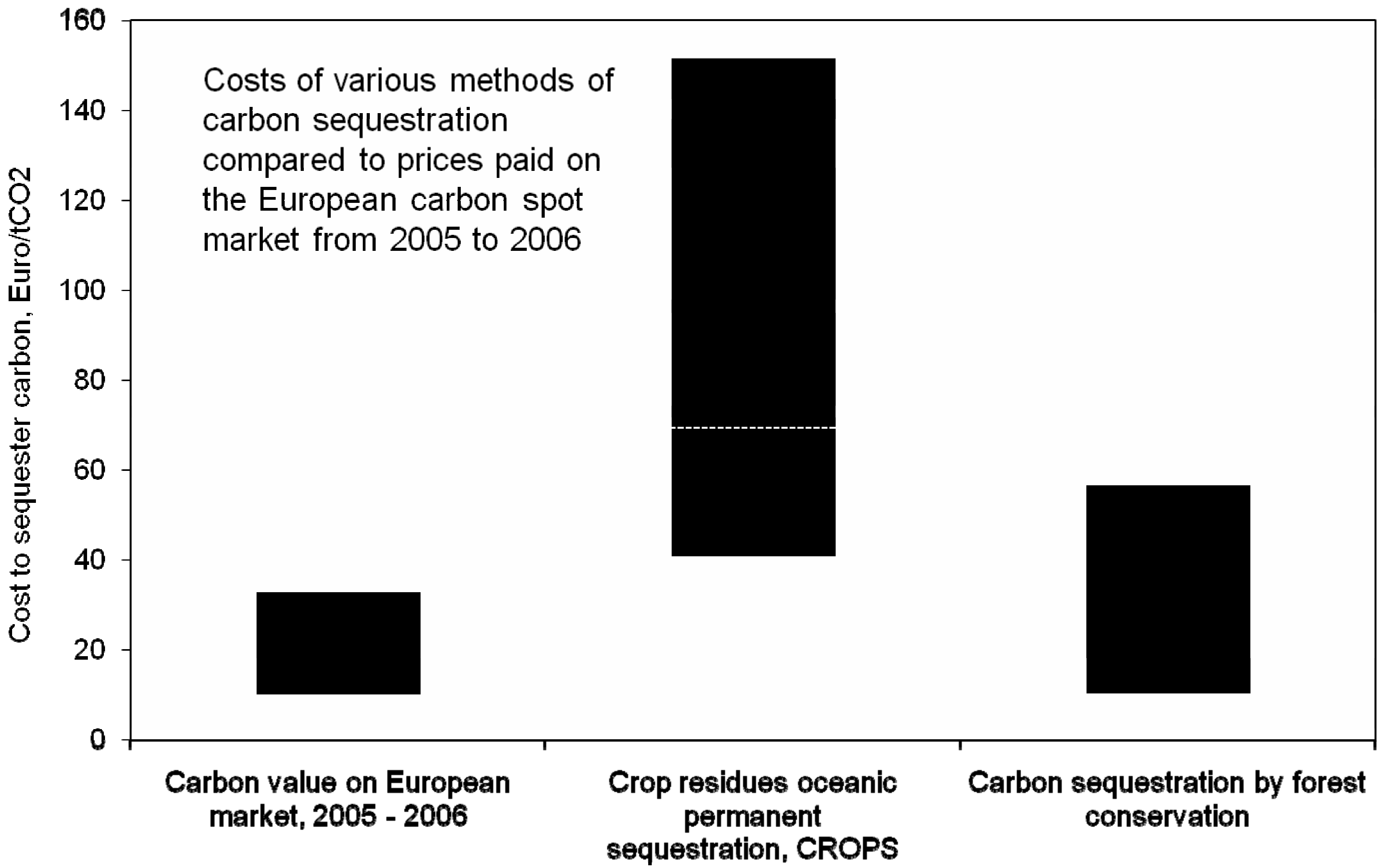
Crop residues can make an immediate and substantial reduction in atmospheric CO_2,
If crop residues are sequestered using CROPS

Cellulosic ethanol production can remove only one third as much carbon from the atmosphere as burial by CROPS



Needed Research

- Determine impacts of crop residues on deep ocean benthic communities
  - Which methods for placing crop residues on ocean floor minimize impact on ocean diversity: concentrated or dispersed?
  - Determine best sites in the deep ocean for crop residue burial
- Determine long term oxidation rates *in situ*
- Determine best methods for ballasting crop residues
- Optimize handling and transport of crop residues


Costs of various methods of carbon sequestration compared to prices paid on the European carbon spot market from 2005 to 2006
Cost to sequester carbon, Euro/tCO2
0
20
40
60
80
100
120
140
160
Carbon value on European market, 2005 - 2006
Crop residues oceanic permanent sequestration, CROPS
Carbon sequestration by forest conservation

Impact on Ocean Floor Habitat

– 5×10^9 m^3 CR annually from US
– Assume CR deposited 1 m deep per year
– Total area required would be 450 km^2
– About one part per million of the Earth's ocean area

Cellulosic Ethanol Production With CO_2 Capture and Sequestration

- CO_2 cannot be captured from ethanol combustion in transportation uses
- CO_2 can be captured from the ethanol production plant
  - Capture efficiency
  - Energy penalty

Carbon Emissions Avoided by Cellulosic Ethanol Production from Crop Residues with Liquid CO_2 Capture and Sequestration

CO2 emissions from combustion, scrubber vent, aerobic vent, losses*		2,036	kmol CO2 C / hr
		24.4	t CO2 C / hr
Corn stover feedstock, crop residue carbon, CR C		37.7	t CR C / hr
		64.8	
Capture efficiency by CO2 sequestration process		85%	t CO2 C captured / t CO2 C processed
C sequestration efficiency compared to feedstock CR		55	t CO2 C captured / 100 t CR C processed
	Low	High	
Energy losses during C capture, estimated*	33%	11%	percent losses due to energy expended during C capture
C sequestration efficiency, energy corrected	37	49	t CO2 C / 100 t CR C processed
Losses due to transport and injection of liq CO2		1.4	t diesel C / 100 t CO2 C injected
Net C sequestration efficiency, CO2 capture compared to feedstock CR	35	48	t CO2 C sequestered / 100 t CR C processed
Net C emission avoidance efficiency due to ethanol production		33.4	t CO2 C sequestered / 100 t CR C processed
Total carbon seqestration and avoidance efficiency	**69**	**81**	**t CO2 C / 100 t CR C processed**

*Aden et al. 2002, Lignocellulosic Biomass to Ethanol Process Design ... For Corn Stover. NREL/TP-510-32438
†http://www.ieagreen.org.uk/presentations/JDcapture.pdf

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